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Energy Efficient Fog Servers for Internet of Things Information Piece Delivery (IoTIPD) in a Smart City Vehicular Environment

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Abstract - **Smart cities are promising solution for providing efficient services to the citizens with the use of Information and Communication Technologies. City automation has become essential concept for improving the quality of the citizens' lives, which gives rise to smart cities. Fog computing for Internet of Things (IoT) is considered recently an essential paradigm in smart city scenarios. In this work, we propose energy efficient Fog Servers (FSs), which delivers the information data to the mobile users (in the vehicle). We introduced the concept of energy efficiency through the judicious distribution of non-renewable or/and renewable energy to the FS, which improves outage (and dropping probability. As a first step, we optimise the locations of the FSs for IoT Information Piece Delivery (IoTPD) in a smart city vehicular environment with dropping less than 5%. Then, we maximised the energy savings by pushing dropping to a certain level (5%). To improve the dropping, the available renewable (wind) grid energy is optimally allocated to each FS. This, in turn, also reduces carbon footprint.**

Keywords —Energy efficiency; Fog computing; Internet of Things (IoT); Renewable Energy; Smart City.

I. Introduction

Due to the unprecedented growth in the infotainment segment, the industry is moving towards the service based abstraction for reducing capital expenditure (CAPEX) [1] and maximising profit sharing. Parallel growth in cities Gross Domestic Product (GDP) drives the researcher towards the paradigms of smart city [2]. Smart cities utilise different catapults. To name a few, these are smart grids, intelligent energy management, health and safety, smart signalling, traffic management, mobile infotainment [3]. The infotainment data is dynamic in nature. Thus, data is largely affected by mobility, number of users and real time applications. To deal with such transiency, the radio range needs to have high bandwidth (and hence shorter distance). With the latest advances on the Internet of Things (IoT), a new era has emerged in the Smart City domain [4], opening new opportunities for the development of efficient and low-cost applications that aim to improve the quality of life in cities. To solve such issue, intermediator devices (between cloud and end users) are needed [5]. These devices in the current context are called Fog Servers (FSs) [6]. In smart-cities, vehicular users play a crucial role in road safety and pollution, thus it is of paramount importance to study the performance of FSs serving vehicular traffic. Currently, the information and communications technology (ICT) sector contributes to 2%-2.5% of the globally emitted carbon, where this figure is expected to increase considerably in near future [7]. Therefore, energy efficiency in the FSs is expected to be an important aspect.

In this paper, we introduce energy adaptive FSs (ADP-FSs) for IoT Information Piece Delivery (IoTIPD). The energy adaptive FSs operate at variable transmission (and networking circuitry) power and therefore can operate at variable data rate. This results in variable piece dropping probability (PDP) throughout the day.

The rest of the paper is organised as follows. In Section II, we describe a smart city vehicular scenario in the Fog computing regime. In Section III, we discuss various optimisation scenarios of non-adaptive and adaptive Fog Servers for energy efficiency with renewable and non-renewable grid energy. These are accomplished by developing Mixed Integer Linear Programming (MILP) models for each cases. Section IV describes the corresponding heuristics. Section V describes and analyse performance results. Finally, the paper is concluded in Section VI.

II. Smart City Vehicular Scenario

In this paper, we consider a smart city vehicular scenario, as shown in Figure 1, where the vehicle movements follow Manhattan Mobility Model [8]. The Internet of Things (IoT) represents a world-wide network of heterogeneous cyber physical objects such as sensors, actuators, smart devices, smart objects, embedded computers. Smart things in the city (IoT objects) such as commercial places, healthcare and educational buildings, and petrol stations are connected to the Fog Servers (FSs). The vehicles request IoT information pieces through a nearby FS. The FSs are connected to the external network via cloud as shown in Figure 1. A vehicle requests an IoT information from any of the neighbouring FSs in a piecewise fashion. The Fog architecture virtually divides the city area into several geographical sectors. These are termed as Internet of Things Domain (IoTD). This architecture ensures that in an IoT domain, a piece gets downloaded from any of the FSs, while the corresponding vehicle is in that IoT domain. This avoids the complicacy of radio handoff management. We consider the IoT piece size to be 2 MB. A FS can accept a maximum of 6 connections, which implies that each IoT Information Piece should be downloaded within 4.5 Mbps service rate (at least) out of 27 Mbps [9] total bandwidth of the FS. The maximum power consumption of the proposed FS (Cisco 829 industrial router) is 30 W [10].

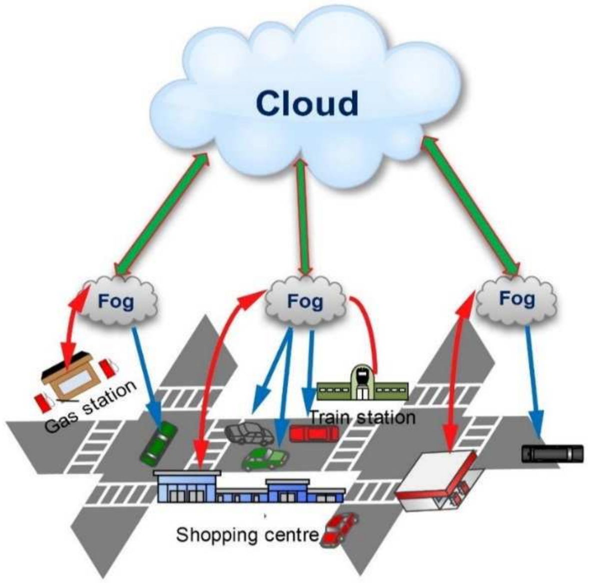


Figure 1: Fog computing for IoT in Smart City Environment.

III. FOG SERVERS FOR IOT INFORMATION PIECE DELIVERY (IOTIPD)

We developed MILP models for optimising the locations of non-adaptive Fog Servers (FSs) with sufficient non-renewable energy. The piece dropping probability (PDP) is thus nil in this case. We then reduce the number of FSs by re-optimising the number of fog servers with the introduction of Piece Dropping Probability (PDP), which is maintained under 5% level. This also minimises the overall energy consumption of the FSs. Note that the FSs here are non-Energy Adaptive (non-adaptive in simpler term), which means that these operate at full energy regardless of the IoT piece demand. The formulation sets, parameters and variables for all the MILP models are defined in Table 1.

Table 1 : List of Notations.

Set	Description
FS	Set of installed Fog computing servers
D	Set of geographical areas (Domain) in the city (IoTD) containing vehicles, IoT Objects and Fog Servers
$IoTD$	Internet of Things Domain
T	Set of time points within an hour
MILP Parameters	**Description**
B^{max}	Maximum capacity of a FS (27 Mbps)
$E_{OP\_Min\_ft}$	Minimum operational energy consumption of FS f at time t
R_{td}	IoT Information Piece Request at d^{th} $IoTD$ at time t
R_f	Total IoT Information Piece requests at FS f
A	A constant, set to 600
MILP Variables	**Description**
ES_f	Energy savings of FS f
α_f	Binary variable, Equals 1 if FS f is ON, equals 0 otherwise
R_{tfd}	IoT Information Piece Request between FS f and $IoTD$ d at time t
δ_{tfd}	Binary variable, Equals 1 if FS f is transmitting IoT Information Piece to $IoTD$ d, Equals 0 otherwise
β_{ft}	Binary variable, Equals 1 if requests at FS f is higher than the maximum capacity of a FS , equals 0 otherwise
E_{TX_ft}	Transmission energy consumption of FS f at time t
$B^{ADP}{}_{ft}$	Adaptive Capacity of FS f at time t
R_{ft}	IoT Information Piece Requests at FS f at time t
$d_{rate-ft}$	Download rate at FS f at time t
Index	**Description**
f	Index of Fog Servers (FS)
d	Index of IoT Domain (IoTD)
t	Index of time points (T)

The FSs in IoTD receive information piece requests from the vehicles in range (D). The MILP model receives these inputs. Thus, the traffic demand (Mb/s) varies at each of these FSs due to vehicular mobility. The effect of discretisation is reduced by adopting a large number of IoTDs. In Section IV, we proposed heuristic which accounts for the vehicular mobility. The corresponding performance results were found to be congruent with the described discretisation approach, which made the MILP modelling possible. The IoT Information Piece demand at each IoTD matrices are used as inputs to the proposed MILP model to find the optimum locations of the FSs. The objective is to minimise the total energy consumption of the FSs over a given time, which enables us to install minimum number of required FSs.

1. Non-adaptive Fog Servers (Non ADP-FSs) powered by non-renewable grid energy

The aim in this case is to minimise the total energy consumption by the FSs over entire time period t. The corresponding MILP model ensures that at each time point, the total traffic is served.

The energy consumption of the FSs f at time t (while they are switched ON) is given by:

$$\sum_{f\epsilon FS} \alpha_{ft} \times (E_{OP\_Min\_ft} + E_{TX\_ft})$$

$$\forall\ t\epsilon T, \forall\ f\epsilon FS \quad (1)$$

The model incorporates minimum operational energy consumption of a FS, while a FS f is switched ON. It includes the energy consumption of the operating circuitry, which accounts for the information collection from the IoT objects. The energy consumption model of the fog server is described as follow. We consider fog servers to be a micro servers (computers) having central processing unit (CPU), Memory and Disk. Minimum operational energy consumption of a Fog Servers comprises of full CPU energy plus half of energy usage of RAM and hard dish. The other half of energy consumption of RAM and hard dish is considered as transmission energy. From [11], we obtained energy usage of CPU is 58%, Memory is 28% and hard disk is 14%. Since the total energy consumption is 30W [10], the minimum operational energy consumption is 23W. Therefore, transmission energy consumption is (30-23 =7 W).

Since, the capacity of a non-energy adaptive FS is fixed, the download rate from a FS is defined as:

$$d_{rate-ft} = \frac{B^{max}}{R_{ft}}$$

$$\forall\ t\epsilon T, \forall\ f\epsilon FS \quad (2)$$

Since the total requests need to be served in each IoTD in this case (without any dropping), the capacity constraint is given by

$$R_{td} = \sum_{f\epsilon FS} R_{tfd}$$

$$\forall\ t\epsilon T, \forall\ d\epsilon IoTD \quad (3)$$

Where the total amount of requests is R_{td} and R_{tfd} defines the requests dealt by the Fog server f of the IoTD d at time t. Equation (3) ensures that at each time point the capacity of a FS is not violated. If the FS has already reached its full capacity, the model proposes installation of another fog server in an IoTD to serve the remaining requests.

2. Non-adaptive Fog Servers with piece dropping probability (Non ADP-FSs+PDP) powered by non-renewable grid energy

In this case, we reduce the number of FSs by considering Piece dropping probability. The IoT piece dropping probability constraint is given by

$$\sum_f (R_{ft} - B^{max}) \Big/ \sum_d \lambda_{dt} \leq 0.05 \quad (4)$$

$$\forall\ f\epsilon FS, \forall\ d\epsilon IoTD$$

which ensures that at each time point, PDP does not exceed 5%. The next constraints are given by

$$R_{ft} - B^{max} \geq\ \beta_{ft}$$

$$\forall\ f\epsilon FS, \forall\ t\epsilon T \quad (5)$$

$$R_{ft} - B^{max} \leq\ \beta_{ft} \times A$$

$$\forall\ f\epsilon FS, \forall\ t\epsilon T \quad (6)$$

where equations (5-6) ensures that if the demand corresponding the requests at FS f is higher than its capacity ($PDP > 0$), set the binary variable $\beta_{ft} = 1$, else $\beta_{ct} = 0$. Therefore, download rate is defined as

$$d_{rate-ft} = (1 - \beta_{ft}) \frac{B^{max}}{R_{ft}} + \beta_{ft} \quad (7)$$

Equation (7) would ensure that extra demand at the FSs is going to be dropped.

$$\frac{R_{tfd}}{d_{rate-ft}} \leq\ \delta_{tfd} \times A$$

$$\forall\ f\epsilon FS, \forall\ d\epsilon IoTD\ , \forall\ t\epsilon T \quad (8)$$

Equation (8) ensures that if the requests is non-zero between FS f and IoTD d i.e. $R_{tfd} \neq 0$, then $\delta_{tfd} = 1$.

$$\frac{R_{tfd}}{d_{rate-ft}} \geq\ \delta_{tfd}$$

$$\forall\ f\epsilon FS, \forall\ d\epsilon IoTD\ , \forall\ t\epsilon T \quad (9)$$

Equation (9) ensures that if the requests is zero between FS f and IoTD d i.e. $R_{tfd} = 0$, then there is no connection. Hence, $\delta_{tfd} = 0$.

$$\sum_{d\epsilon IoTD} \delta_{tfd}\ \geq\ \alpha_f$$

$$\forall\ d\epsilon IoTD, \forall\ f\epsilon FS \quad (10)$$

$$\sum_{d\epsilon IoTD} \delta_{tfd}\ \leq\ \alpha_f\ \times A$$

$$\forall\ d\epsilon IoTD, \forall\ f\epsilon FS \quad (11)$$

Equations (10) and (11) ensure that if there is a connection between $FS\ f$ and $IoTD\ d$ at a time point t, then $FS\ f$ is switched ON ($\alpha_f = 1$).

3. Energy Adaptive Fog Server with Maximum Piece dropping probability (ADP-FSs+MAX PDP) powered by non-renewable grid energy

For this scenario, we introduce energy adaptive Fog Servers where transmission energy is adaptive. By introducing a simplistic (linear) relationship between transmission energy and the capacity of a FS, the FS can operate at lower capacity to reduce energy consumption and serve the total requests at the same time. This occurs only when the demand is low. However, it is achieved at the expense of higher piece dropping probability (PDP). Therefore, the PDP constrain needs to ensure that the dropping is kept equal or under 5%. As the main objective of this model is to minimise energy consumption, the PDP is pushed to the maximum (5%) to maximise energy saving.

4. Energy Adaptive Fog Server with Optimum Piece dropping probability (ADP-FSs+OPT PDP) powered by non-renewable and renewable grid energy

In this scenario, we improve the overall PDP of the network and reduce carbon footprint by optimally distributing available renewable energy (RE) according to the IoT information piece demand at each FSs. We utilise renewable (wind) grid energy for this purpose. According to the availability of wind energy [12], the MILP model propose adjusting the capacity of FSs to its appropriate value to serve IoT piece demand with lower energy consumption. The main constrain defined in this scenario corresponds to (i) replacing non-renewable energy (NRE) with RE, (ii) improving PDP by using extra RE, in the case of excess RE.

IV. HEURISTICS

We develop a heuristic to validate four different scenarios for the performance analysis of the Fog Servers (FSs). The corresponding algorithm is shown in Algorithm: IoT Information Piece Delivery. The first case considers non adaptive Fog servers and optimise the locations of these with a supply of fixed amount of non-renewable energy (NRE) which has been described through lines: 3-19 of Algorithm. The second case computes the Piece dropping probability (PDP) for the optimised number of Fog servers with given traffic (IoT Information Piece) demand and maintains PDP below 5%, as described through lines: 20-37. In the third case, we reduce the energy consumption by pushing the PDP at 5% level. Unlike the previous cases, we consider energy adaptive FSs in this case (lines 38-54). Finally, in the fourth case we introduce renewable along with non-renewable energy and optimised the PDP (lines 55-73).

V. PERFORMANCE EVALUATION

In this section, we discuss the performance evaluation of the IoT Fog Servers in an information piece delivery scenario to the city (vehicular) users. We consider five different cases with different combination of non-renewable and renewable energy for non-adaptive and adaptive fog servers. The first case is for illustration purpose, which considers fixed non-renewable grid energy available to the fog servers throughout the day. In this case the locations are non-optimised. The effect of variation of piece demand on Piece Dropping Probability (PDP) is shown in Figure 2. The piece demand for varying hours of the day is derived from the city vehicular traffic profile. Thus, when the demand is low, all the demands are served. At the peak hours, we observe 5% dropping as the fog servers are incapable of serving all the requests.

Figure 2 shows hourly variation of the number of optimised Fog Servers. As the number of FSs get reduced, the PDP is relatively increased. Our proposed MILP model ensures that the peak PDP does not exceed 5%. Whereas, the heuristic algorithm operates with instantaneous knowledge available, which does not restrict installing additional Fog servers. Thus, a relatively higher number of installed FSs is observed in case of heuristic algorithm. Overall, the results of heuristics follow the same trends as that of the MILP model.

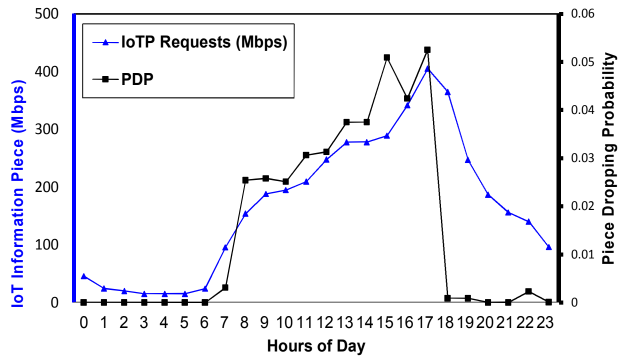


Figure 2: IoT information piece demand in the city and Piece dropping probability.

In Figure 3, the PINK curves (lines for MILP and dots Heuristics) shows the variation of number of FSs for varying hours of the day without any PDP. The RED curves (dashed for MILP and circled for Heuristic) shows the variation of PDP for varying hours of the day, which does not cross the peak value of 5%. Evidently, the number of FSs are more in the former case. This occurs due to the non-adaptive FSs in presence of non-renewable energy. All the curves mostly follow the hourly variation of piece demand.

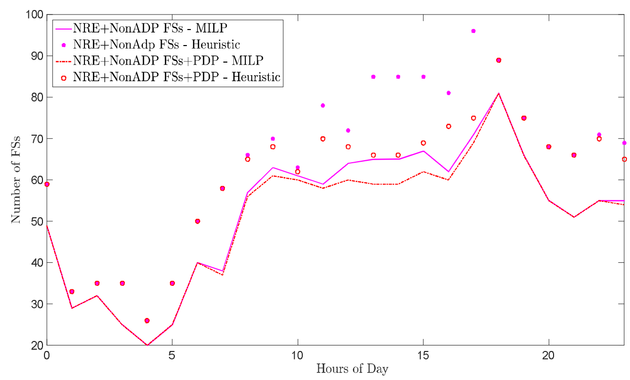


Figure 3: Hourly variation of the number of optimised fog servers.

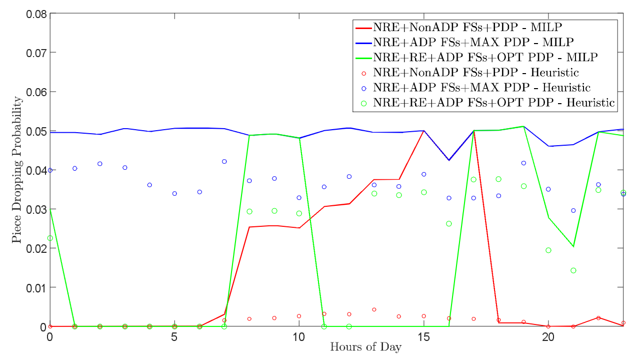


Figure 4: Hourly variation of PDP.

Figure 4 shows different cases corresponding to different combinations of non-adaptive, adaptive FSs with Renewable and Non-Renewable energy. The bold lines are MILP results and the circles are Heuristic results. The RED curves shows the PDP with non-adaptive FSs.

Therefore, it follows the piece demand variation. A minor decrement in dropping (at 19-21 hours) is experienced with adaptive FSs and Non-Renewable energy (BLUE curves). However, with the availability of renewable energy (GREEN curves), which is also varying in nature, the PDP is reduced considerably throughout the day. This also ensures minimum use of NRE. In the case of adaptive FSs (Blue curves), we minimise NRE, which pushes the PDP to the maximum (5%). When the RE is sufficient to turn on the adaptive FSs, they operate at the lowest rate. The PDP, therefore, is the highest (5%). When the RE is sufficient, the PDP reduces to zero. When the RE available to an adaptive FSs varies between its minimum and maximum operating level, the PDP varies between zero and 5%. Here, we use the minimum NRE at each hour of the day. So, the PDP is optimised in that sense. Further, it is observed that the results obtained with MILP model and heuristic algorithm are in good agreement, even though the results of heuristics does not exactly follow the trends of MILP models as the number of FSs in case of heuristics are higher than that of MILP, which has a direct effect on PDP.

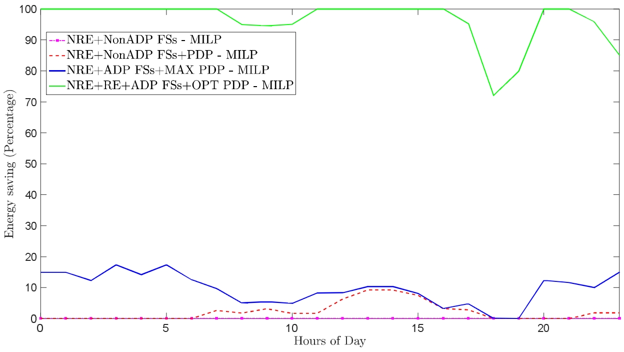
Figure 5 illustrates the total energy savings obtained by respective models at each hour of the day. The Pink line shows the non-renewable energy savings with non-adaptive FSs (which is negligible). The RED DOTTED line shows non-renewable energy savings with PDP, which is marginally better. The BLUE line shows non-renewable energy savings with maximum dropping. This is the best that can be achieved with NRE. The GREEN line shows the best achievable energy savings with optimum dropping. This is possible with the introduction of renewable grid energy and minimisation of non-renewable energy.

VI. CONCLUSION

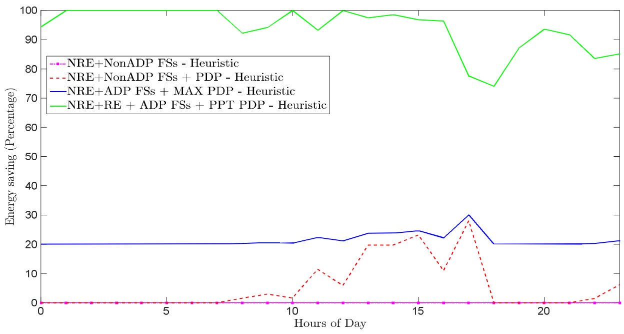
In this paper, we proposed an Internet of Things Information Piece Delivery through Fog servers in city vehicular scenario. We proposed adaptive Fog Servers, which can operate with variable amount of available renewable and non-renewable energy. We studied that with renewable energy, we reasonably maintained dropping within the limit. Further, we conclude that the adaptive Fog servers are much more flexible than the non-adaptive fog servers since they maintain reasonable dropping even with insufficient energy. This is possible because the adaptive Fog servers operate at variable capacity and consumes variable energy. This is achieved at the expense of piece dropping. However, our study showed that dropping can be kept under acceptable level if we judiciously use available renewable energy.

Algorithm: IoT Information Piece Delivery Heuristic

```
Input: IoT Information Piece (IoTP) Requests, AvailableWindEnergy,
NearbyFSs

Output: Number of FSs, EnergySaving, PDP
for all t_1 = 1, 2, 3, ... T_Simulation do
  for all FSs do
    NRE with Non Energy Adaptive FSs CASE:
    if IoTP Requests > 0 then

      Find NearbyFSs
      if Any NearbyFSs is ON& AvailableCapacity > 0
        if IoTP Requests ≤ Available Capacity
          Serve the IoTP Requests
        else
          Turn ON Needed Number of NearbyFSs
          Serve the IoTP Requests
        end if
      else
        Turn ON Needed Number of NearbyFSs
        Serve the IoTP Requests
      end if
    Calculate Number of FSs & EnergySaving
    end CASE
    NRE with Non Energy Adaptive FSs + PDP CASE:
    if IoTP Requests > 0 then

      Find NearbyFSs
      if Any NearbyFSs is ON & AvailableCapacity > 0
        Calculate PDP
        if PDP ≤ 0.05
          Serve the IoTP Requests
        else
          Turn ON Needed Number of NearbyFSs
          Serve the IoTP Requests
        end if
      else
        Turn ON Needed Number of NearbyFSs
        Serve the IoTP Requests
      end if
    calculate EnergySaving & PDP
    end CASE
    NRE with Energy Adaptive FSs + Max PDP CASE:
    if IoTP Requests > 0 then

      Find NearbyFSs
      if Any NearbyFSs is ON & AvailableCapacity > 0
        if IoTP Requests ≤ AvailableCapacity + Max PDP
          Serve the IoTP Requests
        else
          Turn ON Needed Number of NearbyFSs
          Serve the IoTP Requests
        end if
      else
        Turn ON Needed Number of NearbyFSs
        Serve the IoTP Requests
      end if
    calculate Number of FSs & EnergySaving & PDP
    end CASE
    RE+NRE with Energy Adaptive FSs + OPT PDP CASE:
    if IoTP Requests > 0 then

      Find NearbyFSs
      if Any NearbyFSs is ON
        Calculate AvailableCapacity based on RE
        Calculate PDP
        if PDP ≤ 0.05
          Serve the IoTP Requests
        else
          Turn ON Needed Number of NearbyFSs
          Serve the IoTP Requests
        end if
      else
        Turn ON Needed Number of NearbyFSs
        Serve the IoTP Requests
      end if
    calculate Number of FSs & EnergySaving & PDP
    end CASE
  end for
  t_1++
end for
```



(a)



(b)

Figure 5 : Hourly variation of energy savings.

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